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DESIGN OF BUCK-BOOST CONVERTER FOR EV CHARGING APPLICATIONS

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Abstract:

Electric vehicles are gaining popularity as a sustainable mode of transportation, contributing to a greener future. Efficient and reliable charging infrastructure is crucial for the widespread adoption of EVs. One key element in EV charging systems is the DC-DC converter, which interfaces between the power source and the vehicle's battery. This paper presents the design and simulation of a Buck-Boost converter for EV charging applications, implemented using MOSFET technology in MATLAB Simulink.The proposed Buck-Boost converter is designed to accommodate the varying voltage levels encountered in EV charging scenarios, making it suitable for both fast charging and slow charging applications. By optimizing the converter's design and control strategies, we aim to contribute to the development of efficient and reliable EV charging infrastructure, thereby promoting the adoption of electric vehicles and reducing carbon emissions

Keywords -**Buck-boost converter, Dual input DC-DC converter, Versatility, Efficiency.**

I. INTRODUCTION

The adoption of electric vehicles (EVs) represents a significant step towards reducing carbon emissions and addressing the environmental challenges posed by conventional internal combustion engine vehicles. To facilitate the widespread adoption of EVs, the development of efficient and versatile EV charging infrastructure is imperative. At the core of this infrastructure lies the DC-DC converter, a vital component responsible for managing power transfer between the grid and EV batteries.

In the context of EV charging, various challenges must be addressed. These include accommodating different voltage levels and charging scenarios, from rapid charging at public stations to overnight charging at home. To tackle these challenges, the Buck-Boost converter has gained prominence due to its ability to adapt voltage levels, making it suitable for a wide range of EV charging applications.

This paper presents a focused exploration of the design and simulation of a converter tailored explicitly for EV charging. The choice of MOSFET technology, known for its high efficiency and precise control, underscores the commitment to achieving optimal performance in managing voltage fluctuations and load variations typically encountered in EV charging.

The primary objective of this research is to contribute to the advancement of EV charging infrastructure, mission of promoting technological innovation for the betterment of society. By refining the design and control strategies of the

Buck-Boost converter, this study endeavors to elevate the efficiency and reliability of EV charging systems,. This research seeks to provide valuable insights into the design and simulation of Buck-Boost converters for EV charging, thus advancing the realization of a cleaner and more sustainable transportation ecosystem.

II. FLOW DIAGRAM OF THE PROPOSED DC-DC CONVERTER MODEL

A. Elements in the BUCK BOOST for EV charging

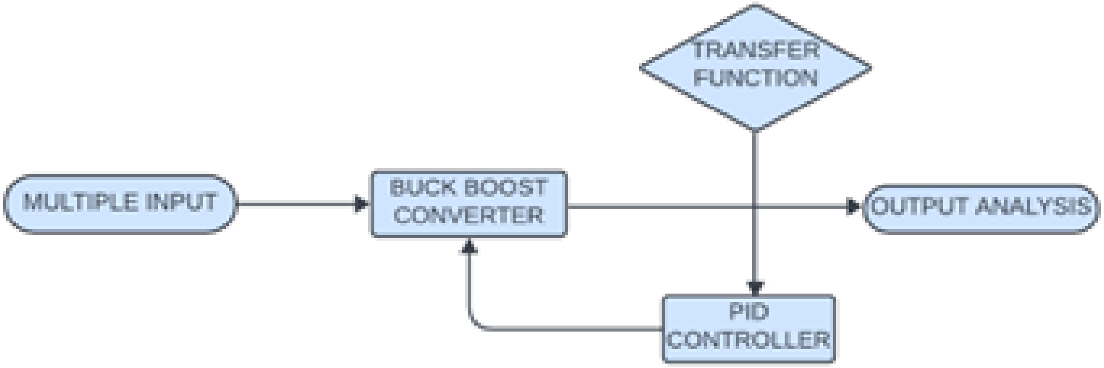


Fig. 1.Dual input converter block Diagram

1. DUAL INPUT FOR BUCK-BOOST CONVERTER:

A Dual Input Buck-Boost Converter represents a sophisticated solution in the realm of power electronics, designed to cater to the diverse requirements of applications that involve multiple input voltage sources and necessitate a regulated output voltage. Its dual-input capability allows it to gracefully adapt to varying voltage levels, accommodating one source with a higher voltage and another with a lower voltage. This adaptability makes it particularly indispensable in several critical domains.

For instance, in the realm of electric vehicles (EVs), where power sources fluctuate between the vehicle's battery pack (typically higher voltage) and regenerative braking systems (often lower voltage), the Dual Input Buck-Boost Converter serves as an essential component. It ensures efficient energy transfer between these sources, effectively charging the battery while delivering power for the vehicle's systems, thereby enhancing overall EV efficiency and range.

In the context of renewable energy systems, such as solar and wind power, where input voltages are subject to variations due to environmental conditions, this converter optimizes power utilization. It efficiently manages these fluctuations and interfaces with energy storage systems like batteries, ensuring a consistent and reliable energy supply.

Uninterruptible Power Supplies (UPS) are another application area where the converter shines. UPS systems frequently switch between utility power (higher voltage) and backup batteries (lower voltage) to provide seamless power delivery to critical loads. The Dual Input Buck-Boost Converter smoothly transitions between these input sources, maintaining a stable output voltage and safeguarding vital equipment from power disruptions.

Moreover, it is invaluable in portable electronic devices that can be powered by different sources, such as batteries (lower voltage) or external adapters (higher voltage). By providing a consistent power supply, it ensures reliable device performance, extending battery life in the process.

Energy harvesting, which harnesses energy from sources like solar panels or piezoelectric generators, relies on this converter to efficiently manage varying input voltages and store energy in batteries or capacitors.

Lastly, in hybrid power systems that amalgamate diverse energy sources the Dual Input Buck-Boost Converter optimizes power extraction and utilization from these sources. It plays a pivotal role in balancing and coordinating the contribution of source to meet power demands efficiently.

In essence, the versatility of the Dual Input Buck-Boost Converter makes it an indispensable component in systems that necessitate efficient and adaptive power conversion between two distinct input sources. Its seamless switching between buck (step-down) and boost (step-up) modes ensures optimal utilization of available energy sources, improved system reliability, and enhanced overall system efficiency. This converter stands as a testament to the remarkable strides in power electronics, enabling innovation across various domains and contributing to a more sustainable and reliable future.

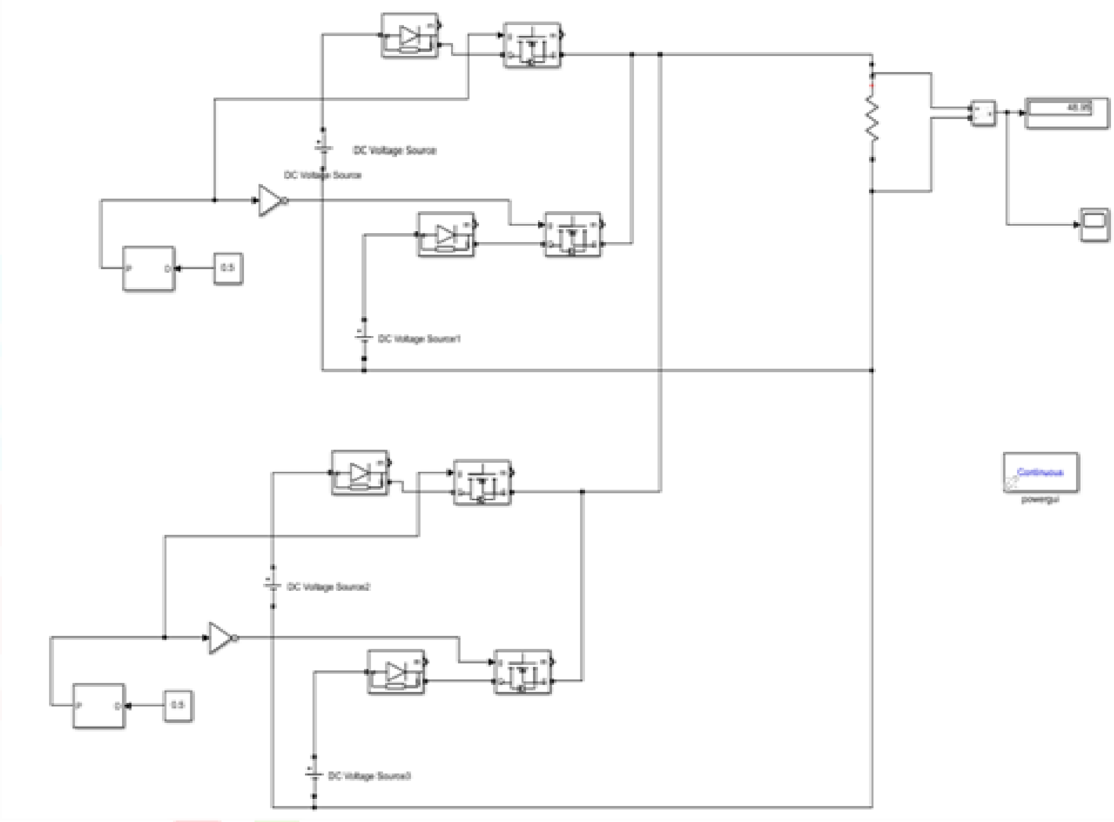


Fig. 2. Model of Equivalent circuit of dual-input

2. BUCK BOOST CONVERTER:

Designing a buck-boost converter for electric vehicle (EV) charging involves selecting the right topology and components to efficiently handle variable input voltages from sources like PV or regenerative braking, while delivering a controlled output for charging. A robust control strategy, such as PID controllers, is essential for precise voltage and current regulation and minimizing switching losses. Safety mechanisms, adherence to standards, and scalability considerations are crucial. Thorough testing, documentation, and compliance with industry standards round out the process, making it a complex endeavor requiring expertise in power electronics, control systems, and safety protocols to create efficient and safe EV charging solutions.

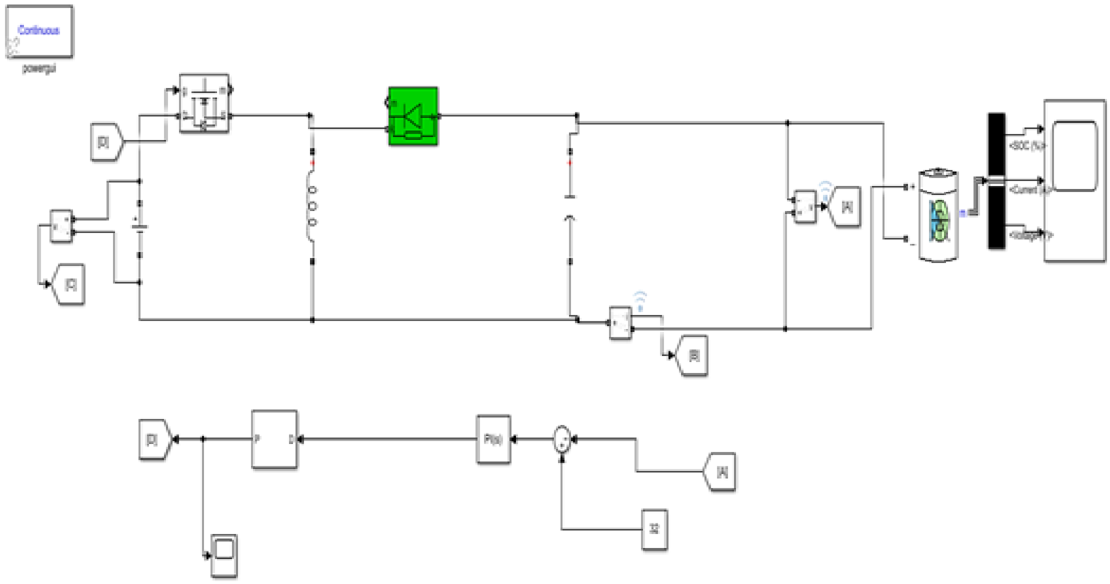


Fig. 3. MATLAB Model of Buck-Boost converter

3. PID CONTROLLER:

The design and implementation of a PID controller in the context of electric vehicle (EV) charging, especially with a buck-boost converter, is of paramount importance for achieving precise control and optimizing the charging process. The PID controller, composed of three key components - Proportional (P), Integral (I), and Derivative (D) - plays a pivotal role in ensuring that EVs are efficiently and reliably charged.

The Proportional component (P) of the PID controller acts as an immediate responder to errors. It continuously compares the actual output voltage and current with predefined setpoints. Whenever deviations from these setpoints are detected, the P component generates an output signal proportionate to the magnitude of the current error. This swift response allows the buck-boost converter to adapt quickly to variations in load conditions or disturbances in the input voltage, maintaining the desired output voltage and current with remarkable precision.

Complementing the Proportional component, the Integral component (I) eliminates steady-state errors. By accumulating historical error values over time, the I component calculates an output signal proportional to the integral of these errors. This function is particularly crucial in EV charging, where charging sessions may extend over extended periods. The I component ensures that the system reaches and maintains the desired output voltage and current levels consistently, regardless of initial deviations or fluctuations. It acts as a "learning" mechanism, correcting for long-term discrepancies and ensuring sustained accuracy.

The Derivative component (D) enhances the system's transient response. It does so by monitoring the rate at which the error signal changes and generating an output signal proportional to this rate of change. In the context of EV charging, where seamless transitions between various charging phases are essential, the D component ensures that the system adapts smoothly to abrupt load changes or disturbances in the input voltage. This prevents voltage and current spikes, resulting in a more stable and safe charging experience for the EV.

Tuning these PID parameters is a critical step in the design process. Properly adjusting these parameters ensures that the PID controller's response aligns precisely with the specific requirements of the EV charging application. Overly aggressive settings can lead to instability and potential damage to components, while overly conservative settings may result in sluggish responses and deviations from the desired charging profile, potentially dissatisfying users.

In the realm of EV charging, a well-tuned PID controller is instrumental in achieving optimal charging performance. It minimizes voltage and current fluctuations during the charging process, critical for the battery's longevity and overall charging safety. Moreover, it significantly contributes to the energy efficiency of the charging system, reducing energy wastage and making EV charging both economically viable and environmentally sustainable.

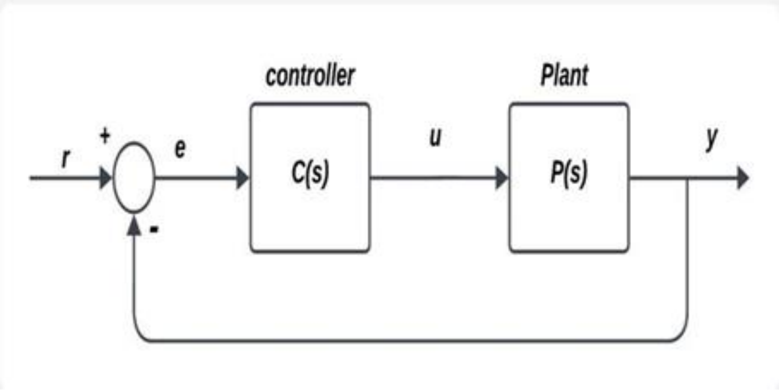


Fig. 4. PID controller block

3. TRANSFER FUNCTION:

Designing the transfer function for a buck-boost converter in the context of electric vehicle (EV) charging is a fundamental step in understanding and optimizing its dynamic behavior. The transfer function serves as a mathematical representation of how the converter responds to changes in its control input, typically the duty cycle of the converter's switches, and translates it into changes in the output voltage. This understanding is crucial for achieving precise control and efficient operation in EV charging applications.

The transfer function is derived from the converter's circuit equations, considering the values of its components and their interconnected relationships. It enables engineers to model and analyze the impact of varying input voltages and load conditions on the output voltage. By manipulating and fine-tuning this transfer function, engineers can design a buck-boost converter that effectively regulates the output voltage and current, catering to the specific requirements of charging electric vehicles.

The transfer function also informs the development of control strategies for the buck-boost converter. Understanding how the control input affects the output voltage allows engineers to design control algorithms that maintain precise regulation, adjust to load variations, and respond to changes in input voltage. This is particularly vital in EV charging, as it ensures that electric vehicles receive a consistent and safe charging experience.

Designing the transfer function for a converter in EV charging applications is a fundamental and intricate process that underpins the development of efficient, stable, and reliable charging solutions for electric vehicles. This mathematical representation enables engineers to understand and optimize the converter's dynamic behavior, guiding component selection, control strategy development, and PID controller tuning.

The DC-DC Buck-Boost converters state space modeling approach

State space module:

$$y(s) = C\left[[SI - A]^{-1}[A_1 - A_2]X + [B_1 - B_2]V_g\right]d(s) + [C_1 - C_2]xd(s)$$

Buck-Boost Converter State Space Model

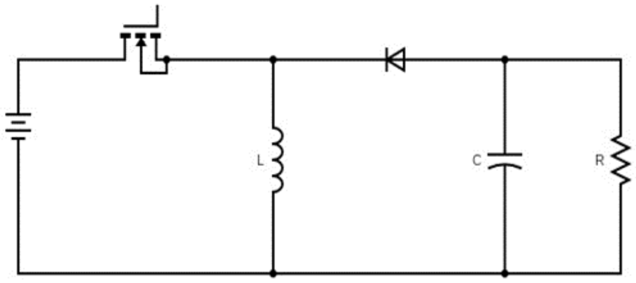


Fig. 5.Buck Boost converter Fundamental circuit

When the switch is ON:

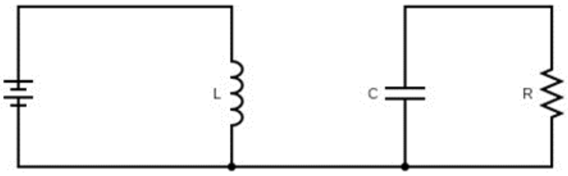


Fig. 6.Buck Boost converter in ON state

During ‘ON’ state, the inductor is charge through V_{in} defined in below.

$$i_L + i_o = 0$$

$$\frac{dv}{dt} = -\frac{v_c}{RC}$$

The state space matrix for converter in ‘ON’ state can be formulated using the above equation

$$[i_L\ v_c\ ] = \left[0\ 0\ 0\ -\frac{1}{RC}\right][i_L\ v_c\ ] + \left[\frac{1}{L}\ 0\right] v_{in}$$

When the switch is off

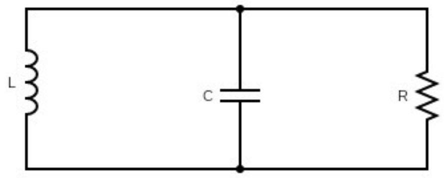


Fig. 7.Buck Boost converter in OFF state

During ‘OFF’ state, the buck boost converter switch is in ‘OFF’

$$-i_L + i_C + i_o = 0$$

$$C\frac{dv}{dt} = i_L - \frac{v_C}{R}$$

The state space matrix for converter in ‘OFF’ state can be formulated

$$[i_L\ v_c\ ] = \left[0\ \frac{1}{L}\ \frac{-1}{C}\ -\frac{1}{RC}\right][i_L\ v_c\ ] + [0\ 0\ ]v_{in}$$

Formulate the state derivative From equation 1 & 2

When input voltage is considered as zero, v_g=0

solving the state space model equation

$$y(s) = \frac{1}{s\left(s+\frac{1}{RC}\right)+\frac{(1-D)^2}{LC}}[0\ 1\ ]\left[S + \frac{1}{RC}\ \frac{(1-D)}{L}\ \frac{-(1-D)}{C}\ S\ \right]$$

$$y(s) = \frac{-(Dv-v_c-D^2v+D)}{LC} + \frac{i_L}{L}\boldsymbol{S}$$

TRANSFER FUNCTION OF THE BUCK BOOST CONVERTER

$$y(s) = \frac{\frac{(D^2v+D(v-1)-v_c)}{LC} + \frac{i_L}{L}S}{s^2+\frac{S}{RC}+\frac{(1-D)^2}{LC}}$$

III. PROPOSED METHODOLOGY

The system is mostly made up of the following:

A converter is used to stabilize and efficiently convert power in a various-input buck-boost converter for Electric Vechicle charging applications. By analysis of different switching devices for converters to reduce losses and efficient simulated in the MATLAB simulink and Lt-spices.

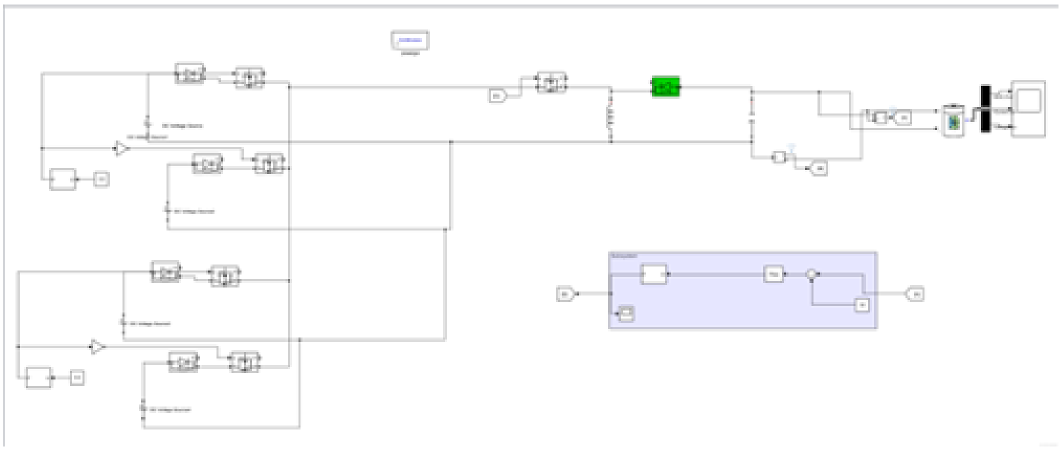


Fig. 8. Model of Dual Input Buck_Boost converter for EV charging

1) Selection of the Component Sizing for the Buck-Boost Converter :

Designing a buck-boost converter for electric vehicle (EV) charging is a most defacult task that requires careful consideration of various factors and precise component sizing. The key components involved in this process include inductors, capacitors, and power switches. Each of these components plays a important role in ensuring efficient and reliable voltage regulation during EV charging, thus contributing to overall performance and safety.

The size of the inductor used in the buck-boost converter is critical as it directly impacts voltage stability and ripple reduction. The inductor stores energy during the charging phase and releases it during the discharging phase. By carefully selecting the inductor's value, engineers can ensure that the voltage remains stable and free from significant fluctuations or ripples.

Another important consideration in the design of converter is the selection of the switching frequency. The switching frequency determines how quickly the power switches turn on and off. Capacitors are another crucial component in the buck-boost converter design. They are responsible for smoothing out the voltage ripple and meeting the load current requirements. The size of the capacitors is determined by the desired voltage ripple and the maximum current that the converter needs to handle.

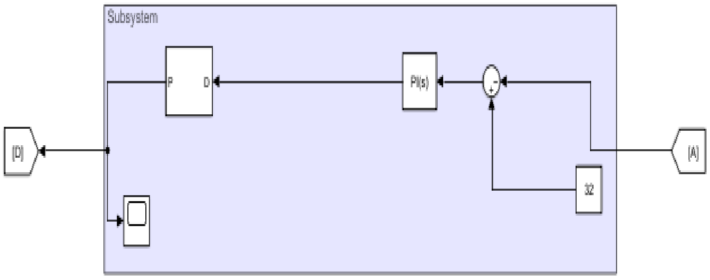
```
s=tf('s');
vinmin=25;
vinmax=50;
vin=(vinmin+vinmax)/2;
vout=-32;
fs=10e3;
I=(p)/vout;
ESRCi=8e-3;
ESRC=5e-3;
Ilipp=(10/100)*(p/vin);
vlpp=(5/100)*vinmin;
vopp=(10/100)*vout;
D=-vout/(-vout+vinmin);
L=(vin*D)/(Ilipp*fs);
IL=abs(I/(1-D));
cl=(IL*D)/(fs*((vlpp-Ilipp)*ESRCi));
co=(I*D)/(fs*(vopp-(IL+(Ilipp/2))*ESRC));
R=vout*vout/I;

k=IL/co;
m=(((square(D))*(vin-D)*(vin-1))+vout)/(L*co);
n=R*co;
p=L*co;
d=square(1-D);


num = [k, m]
den = [1,1/n,d/p]
sys = tf(num,den)
```

Fig. 9. Components sizing calculations

2) PID Controller Strategy:

A PID controller, a cornerstone in control systems engineering, continuously monitors and adjusts the control output based on the difference between a desired set point and the actual process variable. Its three components PID contribute uniquely to its performance: proportional for immediate response, integral for steady-state error elimination, and derivative for future error anticipation. Tuning PID controllers for optimal performance involves adjusting these components, a complex task often requiring proportional, integral, and derivative gains' careful calibration to achieve desired control behavior.

The process of tuning PID controller parameters starts with optimization methods like Auto tuning . Upon completion, these tuned parameters are seamlessly integrated into the control system. Rigorous testing and validation follow to ensure that the tuned PID controller aligns with predefined control objectives and maintains robust performance across various operational conditions.



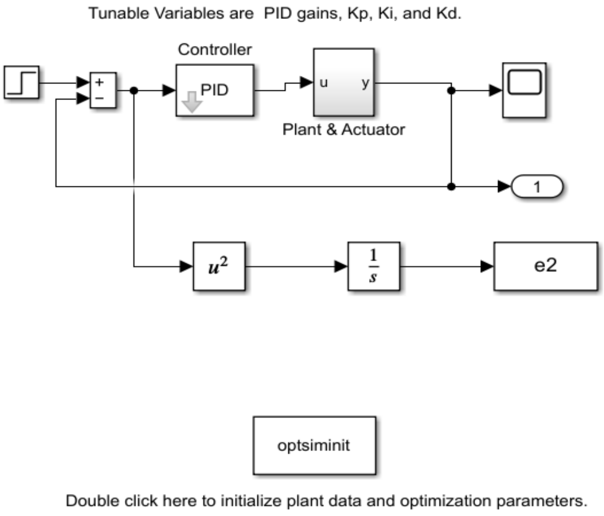


Fig. 10. PID controller Initialize plant

IV. RESULTS AND DISCUSSION

A. SPECIFICATION BUCK BOOST CONVERTER CALCULATED PARAMETERS:

Based on the needs of applications the Resistor, Inductor and capacitor are chosen for our power needs.

Input Voltage	V_{in} = 25V - 50V
Output Voltage	V_{out} = - 32V
Inductor	L = 0.00315789H
Capacitor	C_L = 1.332e-04F
Resistor	R_L = 50Ω
Power	*P =250 W*

B. Auto tuning of PID controller :

To perform PID controller tuning for the converter is tuned based on the error analysis. By using the Undamped pair analysis the value of the P and I is generated

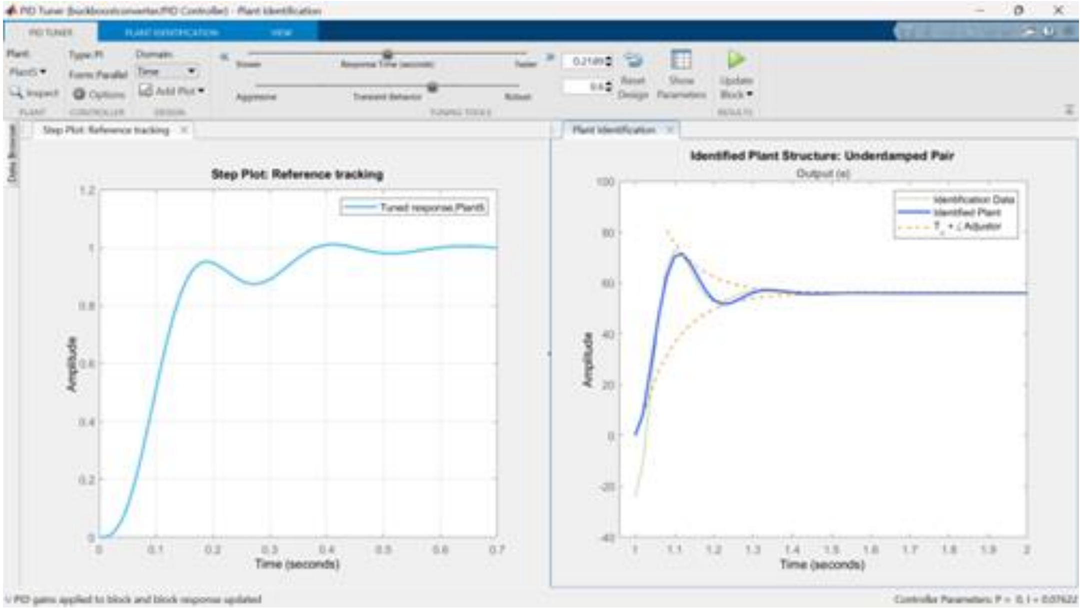


Fig. 11. PID controller auto tuning

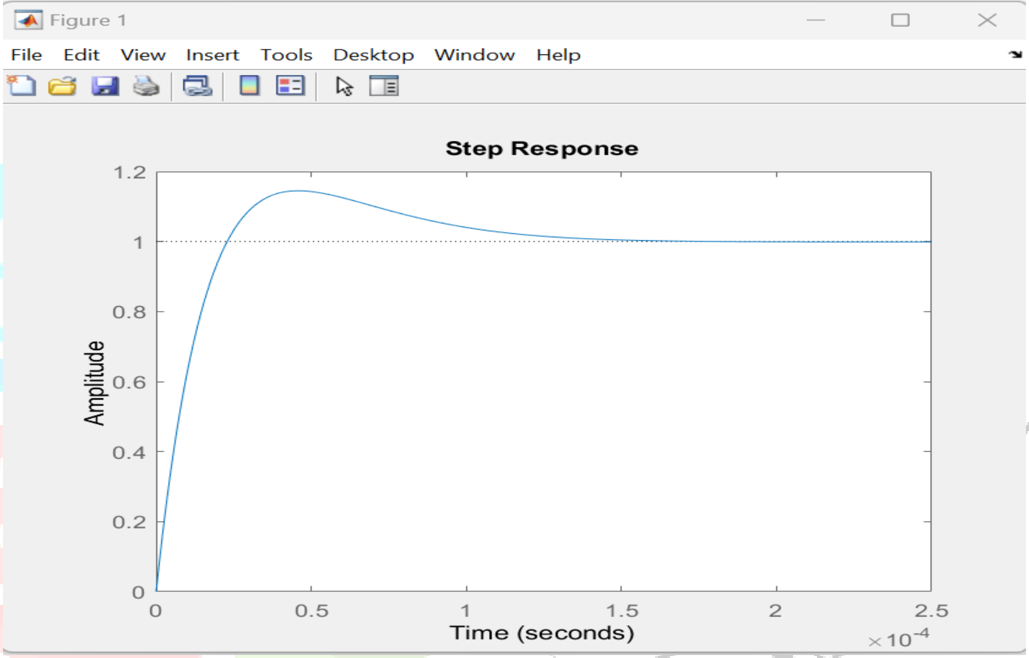


Fig. 12.Step Response of the PID controller

C. Simulation of the system with the single and dual inputs of buck boost converter:

For the EV charging application output power will be a constant based on the battery ratings. The simulation of the Buck-Boost converter below fig based the various inputs and also simulation in multi inputs in the fig . This help to EV charging application how the quality charging is occurs.

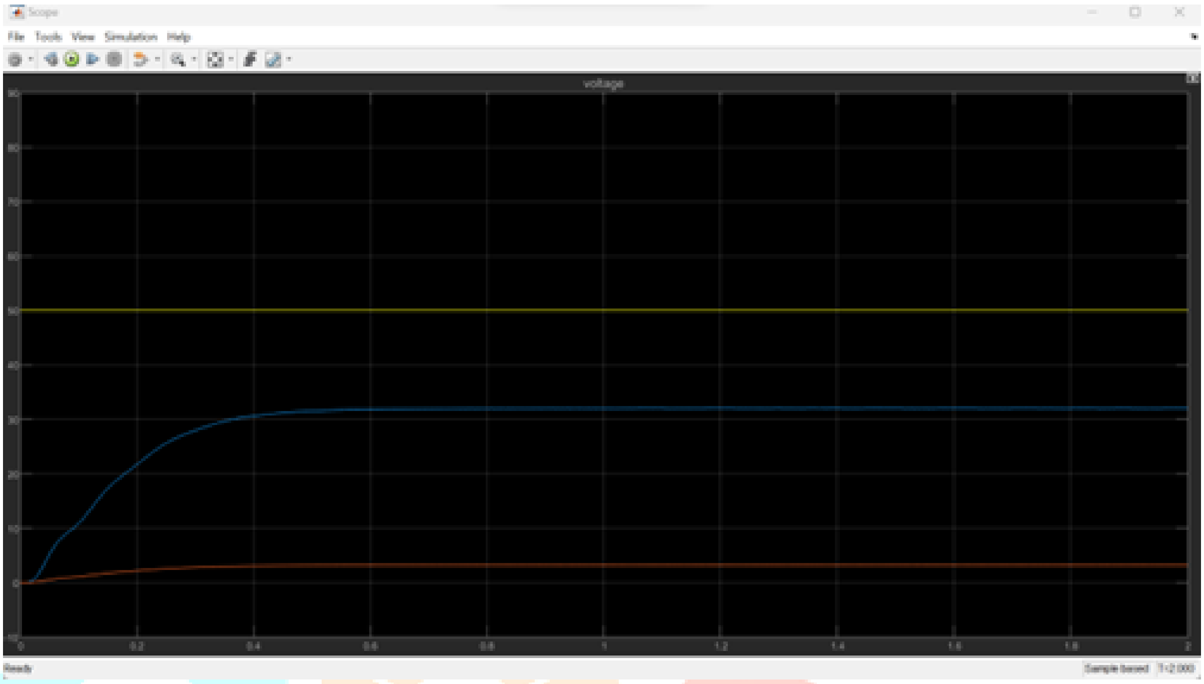


Fig. 13. Buck Boost converter Buck output

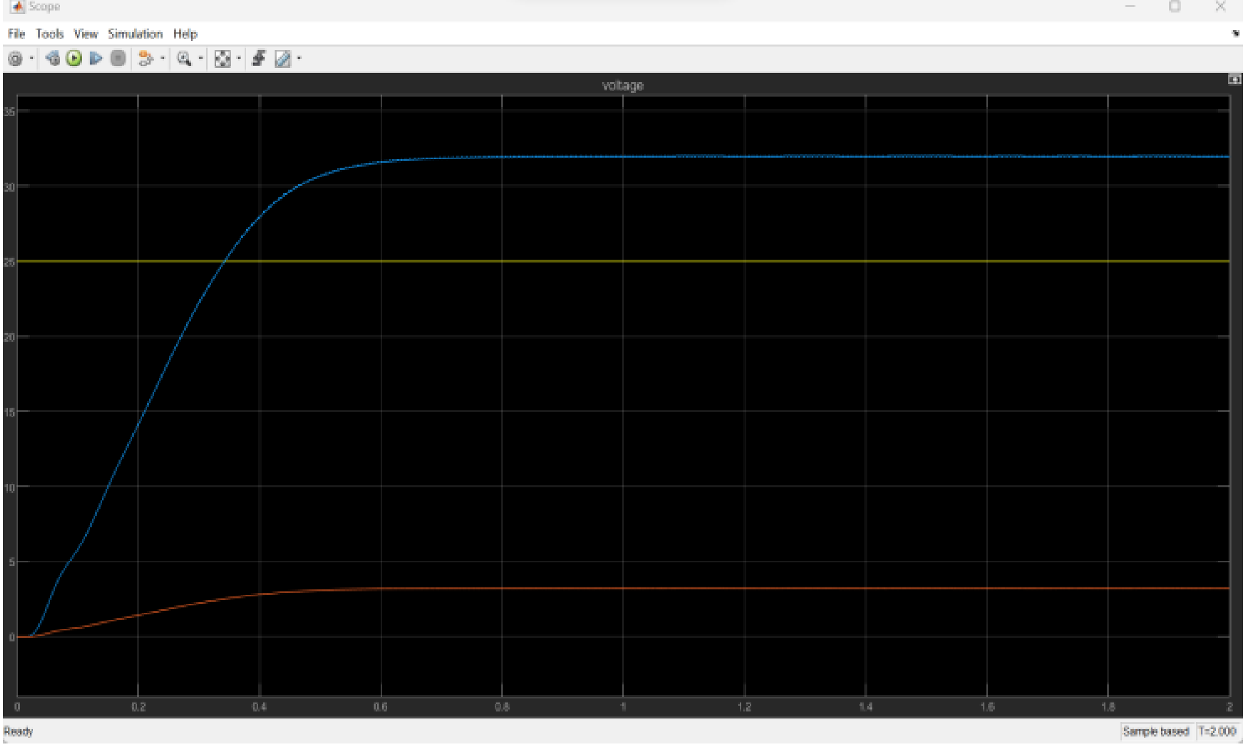


Fig. 14. Buck Boost converter Boost output

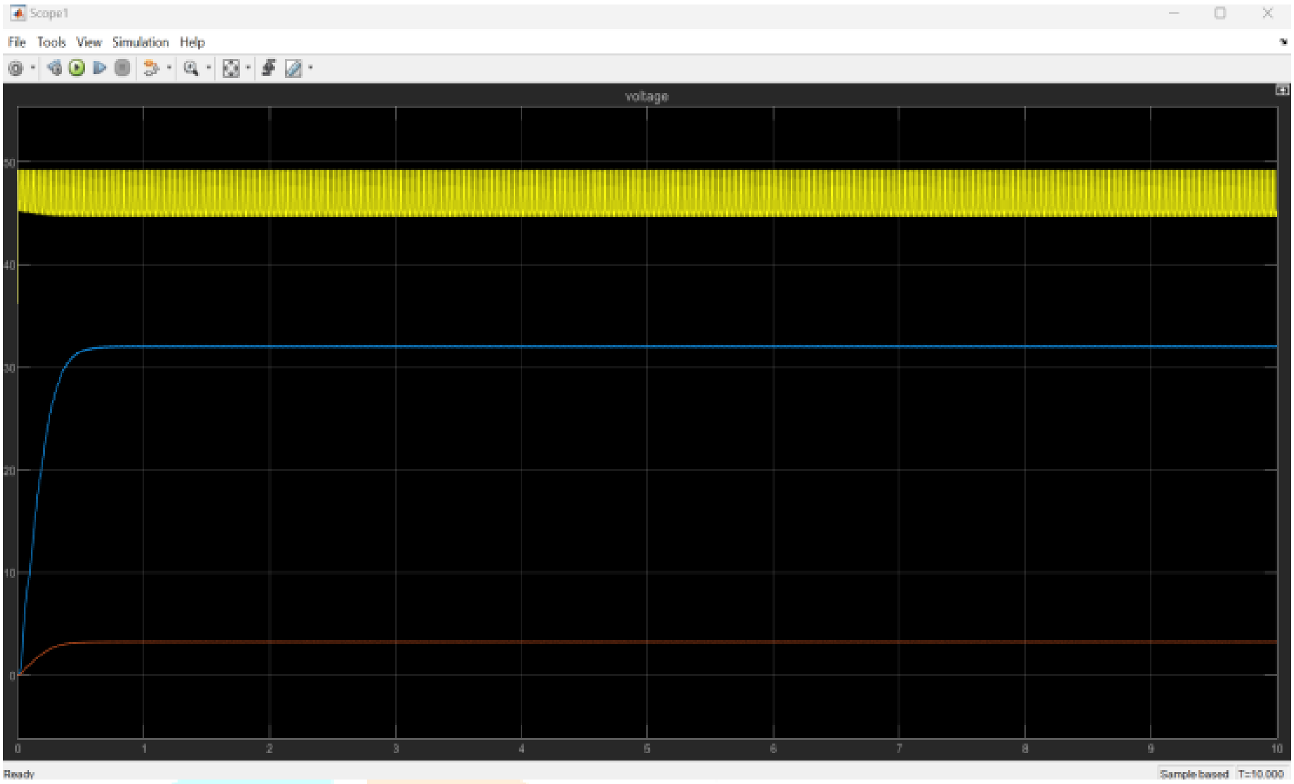


Fig. 15. Duali input to Buck Boost converter Buck output

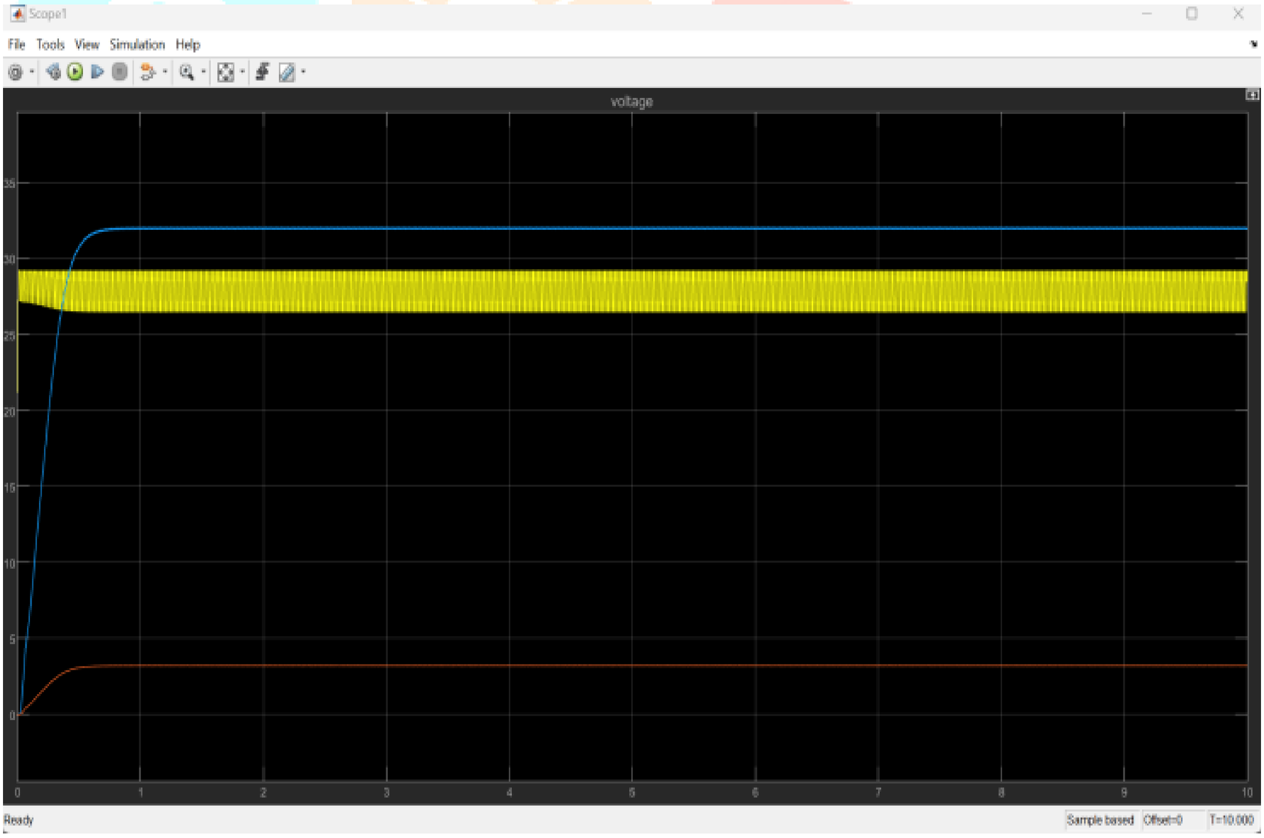


Fig. 4. Dual input to Buck Boost converter Boost output

V. CONCLUTION

In conclusion, our study of the Dual Input Buck-Boost Converter for Electric Vehicle (EV) charging applications, simulated using MATLAB Simulink and employing MOSFET technology, has yielded significant insights and contributions to the field of power electronics and sustainable transportation infrastructure.

Through rigorous simulation and analysis, we have demonstrated the efficacy of the DIBBC in addressing the complex voltage variability challenges encountered in EV charging scenarios. The converter seamlessly manages two distinct input voltage sources, allowing for efficient energy transfer between sources with differing voltage levels.

Our research has showcased the converter's ability to optimize EV charging by efficiently stepping up or stepping down the input voltages, thereby ensuring consistent and regulated output voltage to the EV battery.Furthermore, by utilizing MOSFET technology in the design and control of the DIBBC, we have harnessed the advantages of high efficiency, precise voltage regulation, and rapid switching capabilities. This technological choice aligns with the evolving standards of power electronics in the automotive industry and ensures that the converter operates at peak performance levels.

Our simulations in MATLAB Simulink have validated the converter's performance under various operational conditions, including input voltage fluctuations and load variations. This comprehensive evaluation has provided valuable insights into the converter's efficiency, transient response, and voltage regulation capabilities, confirming its suitability for demanding EV charging applications.

VI. ACKNOWLEDGEMENT

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